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A Hybrid Medium Access Control for Convergence of Broadband Wireless and Wireline ATM Networks

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Abstract—In this paper, we propose a hybrid medium access control protocol for supporting broadband integrated services in the wireless ATM networks. The integrated services include CBR, VBR and ABR traffic varying from low bit-rate to very high bit-rate. The proposed protocol is an excellent compromise of contention, reservation and polling access techniques based on the dynamic TDMA system. Extensive simulation results using realistic data traffic sources, show that the proposed medium access scheme may provide QoS guarantee to different ATM traffic including the realistic MPEG video traces with low cell transfer delay and very high channel utilization of 90%.

I. INTRODUCTION

The third generation wireless communication network will support wideband multimedia services up to 2 Mb/s, while the future wireless network will be required to provide a wide range of multimedia services from very low bit-rate voice to very high bit-rate video. ATM is viewed as a promising method for transmitting broadband multimedia traffic in a single network. For transmitting broadband multimedia traffic in the wireless link, more advanced wireless network is required for converging the broadband wireless links to the ATM based B-ISDN [1], [2]. This demands an efficient medium access control (MAC) protocol to provide end-to-end QoS for a variety of ATM traffic classes, for example constant bit rate (CBR), variable bit rate (VBR) and available bit rate (ABR) traffic.

It is recognized that the wireless ATM networks will mainly support VBR traffic together with some CBR and ABR traffic. VBR traffic such as MPEG video requires very high bit rate with unpredictable burst and tightly constrained QoS requirements. Contrary to the video traffic, CBR voice traffic is a low bit rate and delay sensitive traffic with predictable behavior. Whereas, the characteristic of ABR traffic is much more like VBR traffic without delay and jitter demands, but requires zero cell loss rate. When all the traffic is integrated in the wireless access system, the main difficulty for the MAC protocol is how to efficiently support multi-class services with varied traffic characteristics in the bandwidth-limited wireless channel.

Three main access techniques are used for the MAC protocol, which are contention, reservation and polling. Many published multiple access schemes [3]–[7] combine various access techniques to obtain high channel efficiency. However, it seems very difficult to achieve high throughput

while providing QoS guarantee to CBR, VBR and ABR users at the same time. A hybrid MAC protocol is proposed on the basis of packet reservation multiple access (PRMA) frame structure [6]. PRMA is a statistical multiplexing method for transmitting voice traffic via a time division multiple access (TDMA) system. We are trying to enhance the capability of PRMA for handling broadband integrated service in the wireless ATM networks. The hybrid MAC protocol uses three main access techniques in a proper way to achieve high channel utilization. When the channel load is low, the contention controls the channel access. When the number of connections increases or the channel load is high, the contention starts to have some difficulties for handling the channel access, the polling will take over the channel access control. This makes the protocol very efficient and flexible for supporting a wide range of traffic and achieving a high channel utilization of 90%. Another advantage of the hybrid protocol is that the selection of the system parameters has little impact on the system performance. For example, the permission parameter p of the contention mechanism in the PRMA can be selected in a large range without affecting the system performance, as the polling will compensate for the drawback of the contention mechanism.

The rest paper is organized as follows: In section II, the MAC frame structure for the proposed hybrid access protocol is introduced. Section III discusses the proposed hybrid medium access protocol. Simulation results with realistic data are presented to evaluate the performance of the proposed protocol in section IV. Finally, conclusions are drawn in section V.

II. WATM MEDIUM ACCESS CONTROL

The wireless access system performing the ATM cell transmission through radio link to the fixed ATM network was described in [7]. The MAC frame in support of the proposed hybrid access protocol is shown in Fig.1. A time division multiplexed channel is adopted for statistically multiplexing CBR, VBR and ABR traffic in the wireless channel. The frame is divided into 20 identical time slots. Each time slot is used to transfer one radio packet in the uplink or downlink. The radio packet consists of an ATM cell and radio access protocol overhead that is used for synchronization, ATM cell identification, error detection, acknowledgement and in-band information transmission. The delay in the uplink ACK field is a piggyback information which contains either the buffer delay of the current transmitting ATM cell for CBR and VBR traffic or

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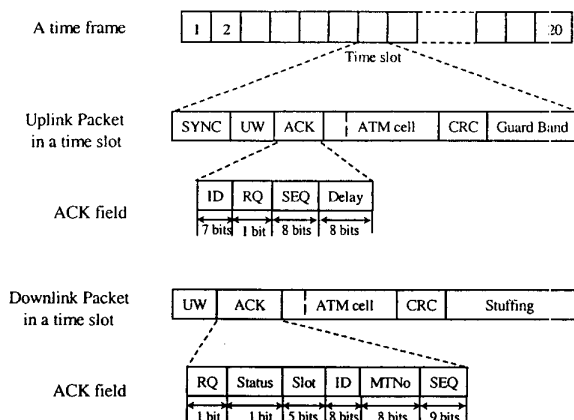


Fig. 1. Medium access control frame structure.

the number of packets needed to be transmitted for ABR and UBR traffic. This message is used by the base station (BS) for efficiently allocating bandwidth to each connection.

During call setup period, the mobile terminal (MT) is required to send the characteristics of the input traffic and their QoS requirements. The BS will decide whether to establish or to reject the new connection based on the current channel load and the demand from the connection. Slot assignment is controlled by the BS, and the status of each uplink slot is broadcast through downlink embedded ACK field.

The bandwidth allocation method for the ATM traffic

proposed in [7] is capable of supporting integrated services with guaranteed QoS and achieving a high channel utilization of 73%. CBR and ABR users are assigned time slots by the BS based on their required bit rate, piggyback information and current channel load. VBR users will contend for available time slots by sending information packets randomly, and each VBR user is allowed to reserve more than one slot per frame according to its current burst and the channel load. Basically, CBR user has the highest priority, and the second priority is assigned to VBR users. However, the efficiency of the access protocol is limited by the contention mechanism for the channel access of the VBR users. Therefore, a hybrid access protocol is proposed to solve this problem.

III. HYBRID MEDIUM ACCESS PROTOCOL

Channel access priorities are assigned to different ATM traffic classes (CBR > real-time VBR (rt-VBR) > non-real-time VBR (nrt-VBR) > ABR/UBR). The channel access methods for CBR and ABR traffic are the same as that proposed in [7], but the access scheme for VBR traffic is modified.

The main characteristic of the VBR traffic is unpredictable burst. Therefore, it is difficult for the BS to efficiently assign time slots to VBR connections based on the burst time and the burst size of each connection without knowing the current states of the buffers distributed in the various MTs. To use the radio bandwidth efficiently, VBR connections should have the opportunity of controlling part of the channel access for adapting the reserved bandwidth to the burstiness of each VBR connection. The concept of this multiple access scheme for VBR traffic is given in Fig. 2.

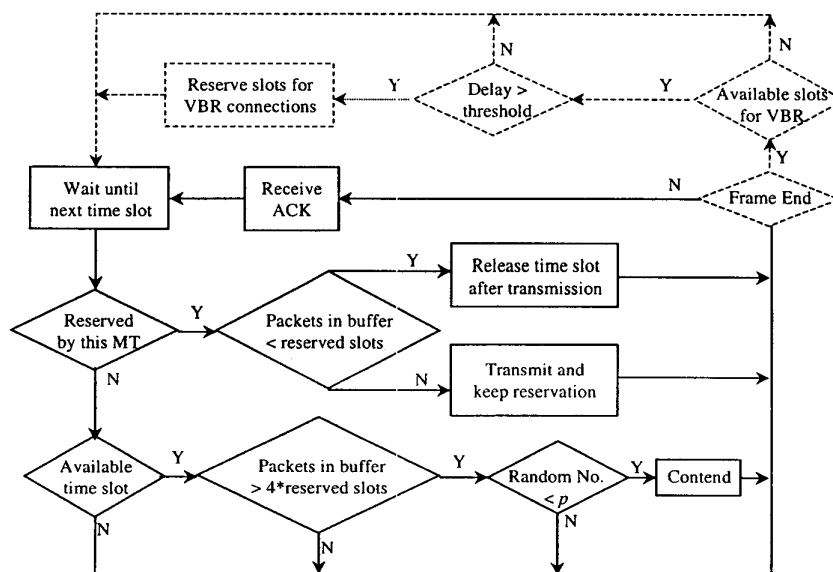


Fig. 2. The concept of bandwidth allocation scheme for the VBR traffic. Solid lines show the contention and reservation mechanisms. Dashed lines show the polling mechanism.

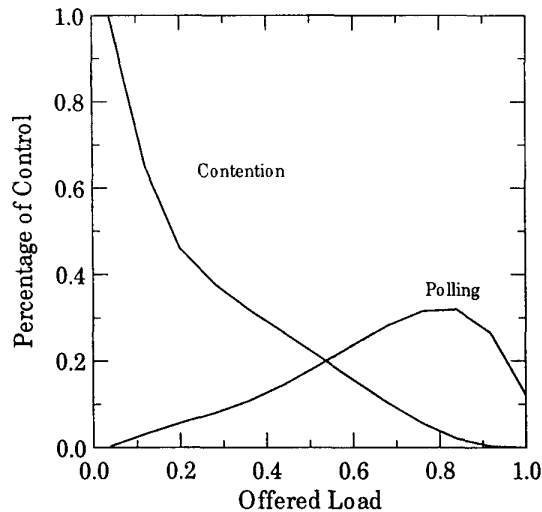


Fig. 3. Percentage of access control versus offered channel load.

The multiple access scheme allows each VBR connection to contend for more than one time slot per frame based on the buffer status of the connection by generating a random number between 0 and 1. The random number is compared with a system parameter p , where p is related to the number of simultaneous active VBR connections. If the random number is less than p , the VBR connection is allowed to send an information packet to contend for an available time slot. Subsequently, the BS will reserve the time slot to the VBR connection for each successful contention. The contention is also controlled by a comparison condition, where the VBR connection is only allowed to contend for an available slot when it has 4 times more number of packets in its buffer than the number of its reserved slots.

Keeping and releasing reserved time slots are controlled by another comparison condition, which is also based on the buffer status. When the number of packets stored in the MT buffer less than the number of slots reserved for the MT, the time slot will be released; otherwise the VBR connection will keep the reservation in the next frame.

Those contention and reservation mechanisms give both freedom and limitation to VBR connections for using the available wireless bandwidth. The p parameter is used to reduce the probability of collision. The comparison conditions make the bandwidth allocation to all the VBR connections with fairness. However, due to the limitation of contention and reservation techniques, a polling method is added at the end of each frame, which is shown in the upper part of Fig. 2 with dashed lines.

At the end of each frame, after the assignment of slots to CBR connections and after the contention and reservation of slots by VBR connections, the BS knows how many time slots that are still available due to collisions, no contention and no assignment. In order to assign those available time slots efficiently to the connections that need them most, the BS stores the delays of the last transmitted packet from each

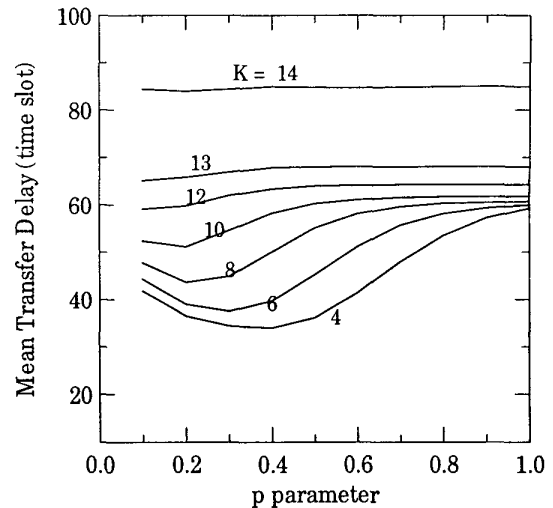


Fig. 4. Mean transfer delay versus p parameter. K is the number of VBR connections.

VBR connection. The delay includes the buffer delay of the last packet and the elapsed time since the last packet is received. If the delay is longer than a threshold, the BS will reserve an available time slot for the connection according to its access priority. The threshold is related to the traffic characteristics and QoS parameters, such as the mean cell rate and the maximum delay tolerance, which can be known at the call setup period.

Since the reservation is made after the successful contention and polling, only the roles of contention and polling for controlling the VBR traffic access to the wireless channel are discussed. Fig. 3 gives an example of the different roles of contention and polling for allocating bandwidth to the VBR traffic. When the channel load is low, the contention is able to allocate the available bandwidth to each connection fast enough. However, when the channel load is high, the contention cannot work properly due to high collisions if the parameter p is large, or due to not enough contention if the p is small. The polling starts to play an important role on allocating the bandwidth efficiently to the connections for achieving a very high channel utilization of 90%. It can be seen that the polling does not completely compensate for the access control of the contention. The reason is that when the bandwidth is assigned to a connection for the data transmission via successful contention and polling, the reservation will help to keep the assigned bandwidth to empty the data buffer of the connection. In particular, when the traffic load of each connection is high, the reservation takes more effect.

The polling method not only compensates for the drawback of the contention method but also makes the p parameter having little impact on the system performance. Fig. 4 shows mean transfer delay of VBR traffic versus the permission parameter p with different number of VBR connections K . When K is less than 14, the QoS requirements of VBR connections are satisfied. It can be

TABLE I.
SIMULATION PARAMETER VALUES

Information channel rate	25 Mb/s	Max delay of CBR	5 ms
Slots per frame	20	Max delay of VBR	20 ms
Frame duration	340 μ s	Number of CBR connections	16
Slot duration	17 μ s	Number of ABR connections	12

seen that there is a wide range for selecting a suitable p value to meet the same QoS requirements. Therefore, the choice of p value is not critical as in the PRMA-based protocols.

IV. PERFORMANCE

A simulation system is written in C++ for evaluating the proposed hybrid medium access protocol. Three kinds of traffic classes are considered at the same time in the simulation, which are 64 Kb/s CBR voice, 1 Mb/s ABR Internet access and MPEG-1 rt-VBR video. The MPEG-1 video traffic uses real traces available at the FTP site [8], [9] to make the evaluation as realistic as possible. Each MPEG-1 trace is 40,000 frames duration with frame rate of 25 frames per second, and the traces are from different TV programs and movies encoded with a group of picture (GoP) size of 12. CBR sources are generated periodically according to the peak cell rate (PCR). ABR traffic sources are generated using leaky-bucket proposed in the ATM Forum. It is assumed no new call arrives and no old user disconnects during the simulation period, and only uplink is focused. MPEG-1 traces with random start point are added gradually to the wireless channel to change the channel load. The numbers of CBR and VBR connections are fixed to 16 and 12, respectively. Table I gives simulation parameter values.

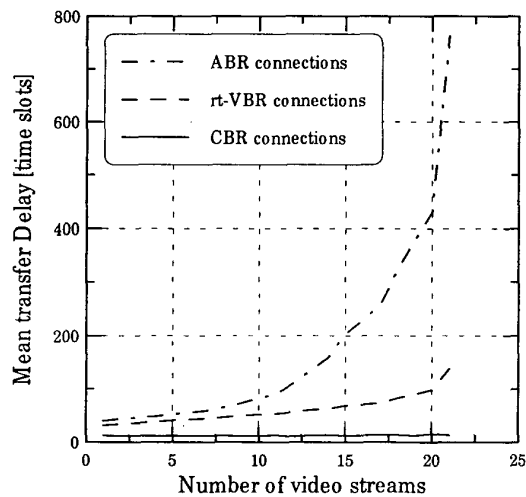


Fig. 5. Mean packet transfer delay for CBR, rt-VBR and ABR connections.

Fig. 5 plots the mean packet transfer delay versus the number of active video streams. Since the channel access priority is set as CBR > VBR > ABR, CBR connections experience the lowest mean transfer delay, while the ABR connections suffer from the highest delay. It is observed that the delay of CBR connections almost keeps the same, whereas the transfer delays of VBR and ABR connections increase with a rise in the number of video streams, especially the delay of ABR connections increases rapidly as the channel is getting crowded.

The packet loss ratio of rt-VBR and ABR connections against the number of active video streams is given in Fig. 6. The packet loss ratio of CBR connections is less than 10^{-8} , which can not be plotted in the figure. When the delay of a CBR packet is more than 5 ms, the packet will be dropped. The packet life time for the rt-VBR video is 40 ms. Although ABR traffic has no delay requirement, the packet will be dropped if the delay is longer than 500 ms. Packet loss ratio due to the buffer length is not significant. As shown in Fig. 6, rt-VBR connections dominate the overall performance of the proposed hybrid access scheme. It illustrates that the proposed channel access scheme can support up to 19 independent MPEG video connections, 16 low bit-rate voice connections and 12 high bit-rate WWW browsing connections at the same time with equivalent QoS as in the wireline ATM networks.

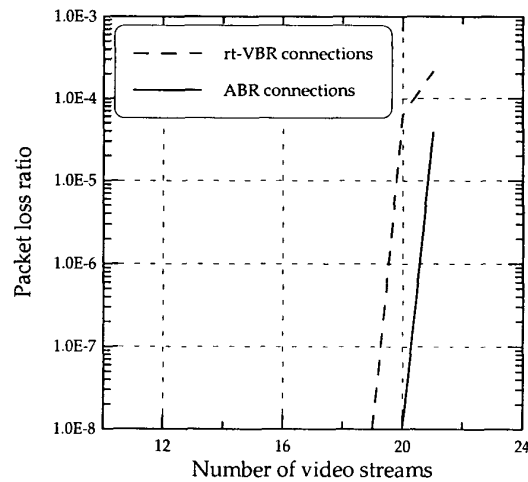


Fig. 6. Packet loss ratio for rt-VBR and ABR connections. Packet loss ratio of CBR connections is less than 10^{-8} .

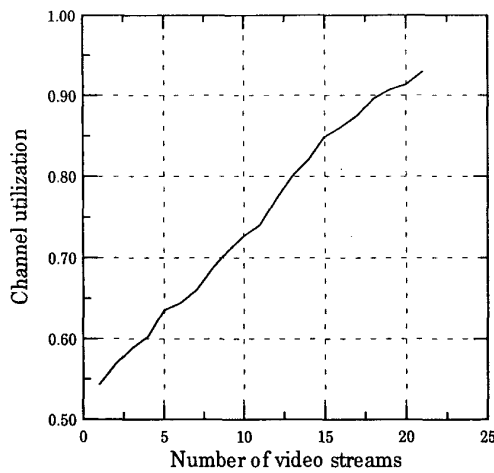


Fig. 7. Channel utilization versus the number of video streams.

Channel utilization against the number of video streams is drawn in Fig. 7. As shown in Fig. 6, the proposed hybrid access protocol can provide guaranteed QoS to all the ATM connections at the point of 19 video streams, which is corresponding to 90% channel utilization given in Fig. 7. It demonstrates that the proposed protocol is very efficient among the published medium access protocols for broadband wireless networks supporting a variety of ATM traffic sources.

Both CBR and rt-VBR traffic have jitter (delay variation) requirements. The jitter distributions of CBR and rt-VBR connections are shown in Fig. 8. It can be seen that the jitter of most CBR connections is within one frame duration of 340 μ s, and the jitter of rt-VBR connections is within 5 frame duration of 1.7 ms. Very small jitter makes the convergence of wireless and wireline ATM networks much easier.

V. CONCLUSIONS

In this paper, we have presented a hybrid medium access control protocol for the convergence of wireless and wireline ATM networks. Simulations with realistic traffic sources have been carried out for evaluating the proposed protocol. All the results show that the proposed hybrid MAC protocol can achieve 90% channel utilization with guaranteed QoS for broadband integrated services including video, voice and data. It also shows that the proposal makes the selection of the parameter p in the PRMA based protocols very flexible and has the potential for efficiently supporting a wide range of telecommunication services in the broadband wireless packet switched networks.

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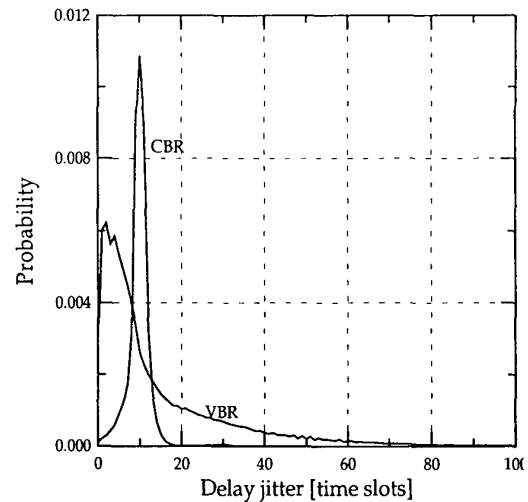


Fig. 8. Jitter distribution for CBR and rt-VBR connections.

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